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A statistical evaluation of the theory of biorhythms

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A STATISTICAL EVALUATION OF THE THEORY OF BIORHYTHMS

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Monterey, California

THESIS

A STATISTICAL EVALUATION OF THE
THEORY OF BIORHYTHMS

by

Louis John Giannotti

September 1974

Thesis Advisor: D. E. Neil

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A Statistical Evaluation of the Theory of Biorhythms

by

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Lieutenant, United States Navy
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

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September 1974

ABSTRACT

This thesis presents an interpretation of the Theory of Biorhythms and develops a combined statistical model for a statistical validation of the theory. The model is then used to investigate a set of intellectual data and a set of accident data. The intellectual data is based upon 112 academic grades taken from four postgraduate school students over a 14 month period. The accident data, taken from insurance abstracts, consists of 66 accidents which occurred at a pulp plant in British Columbia, Canada.

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I. INTRODUCTION

It is currently suggested in scientific theory that life functions of all living organisms are characterized by some form of cyclic nature. Many of the cyclic rhythm theories based on observed human performance have been accepted as fact while others, lacking strong scientific and mathematical proof, have been treated with some skepticism.

The most well-known and best documented of observed human isochronic phenomena are the circadian or daily rhythms. Circadian rhythms vary in length from twenty to twenty-eight hours depending upon the individual and environmental circumstances. Included in these daily or circadian rhythms are life function or regulatory cycles, biochemical cycles, and socio-cultural, work-eat-sleep cycles. Extensive research in the area of circadian rhythms, as reported by Squibb Pharmaceutical Co. [1972], concluded that regulatory and biochemical cycles are extremely rigid. Lengthy experimentation with circadian work-eat-sleep cycles has been conducted by a variety of individuals and institutions including the Max Planck Institute in Germany [Palmer]. Their research originated from two contesting theories. One theory states that the circadian patterned work-eat-sleep cycle is a product of socio-cultural customs while the other theory suggests it resulted from the interaction of the multitude of circadian biochemical and regulatory cycles [Luce, 1973]. Scientists have been conducting experiments in this area for the past

thirty-four years. The experimental prerequisite to remove artifical and natural indicators of time, such as clocks and the rising and setting of the sun, stimulated Dr. Nathaniel Kleitman to conduct his original cave studies, in Mammouth Cave, Kentucky [Luce, 1972c]. In 1962, further studies were conducted by Michel Siffre who spent sixty-three days on a subterranean glacier in Scarasson Cavern in the French Alps. Finally, in 1966, Dr. John Mills analyzed David Lafferty's one-hundred and twenty-seven day isolation in a cave in Cheddar, England. The most controlled experiments were conducted at the Max Planck Institute where eighty-five subjects lived for three weeks in luxurious underground efficiency apartments.

All research yielded the same results that although man can artifically control the length of his work-eat-sleep cycle, the regulatory and biochemical cycles maintain their ritualistic twenty-four hour schedules. Research has also indicated that the regulatory and biochemical circadian rhythms influence physiological responses to environmental stimuli. For example, the body reacts differently to such foreign agents as noise, antibiotics, hypnotics, anaesthetics, and liquor at different times of the day [Squibb, 1972]. It has often been suggested that circadian rhythms are a partial explanation for the commonly observed circadian post-surgical death cycles and spontaneous birth cycles. Since circadian rhythms are constantly observed, the fact that they do exist is generally accepted, but, in some cases, why they exist can

only be hypothesized since the precise roles of many body functions remain a mystery to the medical community.

Cycle analysis has not been limited to the study of circadian rhythms. Recently behavioral scientists have become involved in the analysis and interpretation of patterns of overt human performance. A considerable amount of work has been conducted by physiologists and psychologists in the area of cyclic phenomena of human behavior. Development and application of several emotional measurement devices has led to various mood cycle discoveries. Tedious experimentation and research by Dr. Max Lüscher of Germany led to the original development of the Lüscher Color Test in 1947 which has since been extensively refined. Its validity is based upon several different statistical analyses [Scott, 1971]. Adaptability, ease of application, and lack of rigidity has made it an ideal and instrumental tool of many behavioral scientists, from psychologists to criminologists. Although investigation and clinical observations by Drs. Halberg and Panofsky revealed a wide spectrum of mood cycles, they reported the most statistically significant periodicity was seven days [Luce, 1972b, Brinker, 1973]. Further mood cycle study was conducted by J. A. Dorland [Brinker, 1973]. Using the Dorland Mood Rating Scale, a categorical, subjective, emotional, measurement device, Dorland also noted the presence of a strong seven day mood cycle. Additional investigation of emotional cycles has led to various other mood scales such as Hersey's Rating Scale for Emotions [Brinker, 1972].

Additional research in the areas of emotional disturbances led to more bizarre theories. Statistical studies, conducted by Dr. Arnold Lieber of the University of Miami's Psychiatry Department, based on 1800 murders in Dade County, Florida, show a cyclic murder rate coincidental with the rise of the full moon [Hackler, 1969]. Doctors from the Douglas Hospital in Montreal, Canada have discovered correlation between cycles of intense hostility and violence among mental patients and geomagnetic disturbances caused by sunspots. Many physicians such as Dr. M. Arborlieus of Halmstead, Sweden, believed that the awareness, proper interpretation, and application of physiological and psychological behavior patterns can be of significant importance in accurately diagnosing certain diseases such as ulcers, cancer, and psychosomatic illness [Luce, 1972a].

One of the older cyclical theories, based on observation of human behavior, is the theory of biorhythms developed in the late 19th century by Dr. Herman Swoboda of Switzerland and Dr. Wilhelm Fliess of Germany [Thommen, 1973]. Based on research in psychology and periodicity, the theory states that man is characterized by three inherent cycles called biological rhythms or biorhythms. The three cycles, which include a 23-day physical biorhythm, a 28-day emotional biorhythm, and a 33-day intellectual biorhythm, are indicative of the potential performance capacity of an individual. It is hypothesized that all three biorhythms begin at birth and terminate with death. Swoboda and Fliess' cyclic

hypotheses were based on pure observation. Since the original work of Swoboda and Fliess, various people have explored biorhythms resulting in a variety of conclusions and interpretations.

Wallenstein and Roberts [1973] tested biorhythm validity against the outcome of the 1972 UCLA-USC football game along with selected historical events including Custer's prognosis at Little Big Horn and Babe Ruth's sixty homerun season. Thommen [1973] attacked validity in a similar fashion by analyzing specific historical events biorhythmically followed by a subjective interpretation of the results. Willis [1972] analyzed data which included hospital records, single car accident fatalities and athletic events. He also discussed several cases of current application including the supposed success of the Ohmi Railway Company of Japan in achieving 2,000,000 accident free kilometers since the implementation of biorhythms in driver management. Although the chosen specific examples have corresponded favorably to biorhythmic prediction, this type of analysis does not constitute a proper mathematical validation of the theory. Closer scrutiny of Ohmi's accomplishments may not be so surprising if an analyst properly applied stochastic processes. A time or spatial poisson counting process, which counts events through time in a poisson fashion, could have been applied to predict the probability of achieving 2,000,000 accident free kilometers. Using an estimated accident rate based on past performances it may be entirely possible that

this could have occurred with relatively high probability, prior to the use of biorhythms. The following brief mathematical formulation illustrates the application of a stochastic process to the investigation of the Ohmi situation. To be complete it requires the appropriate data, from the Nagahama Service Center, needed to estimate the accident rate. However,

P(n accidents occur in the interval (s,s+t) =

$$P(N(s+t) - N(s) = n) = P(N(t) = n) = \frac{e^{-\lambda t}(\lambda t)^n}{n!} .$$

For the Ohmi situation: $n = 0$

$t = 1.083$ years

λ = # accidents/given time period

$$P(N(1.083) = 0) = \frac{e^{-\lambda t}(\lambda t)^0}{0!} = e^{-1.083\lambda}.$$

Details of calculations, theoretical assumptions, and the associated postulates are contained in "Introduction to Probability Models" by Ross [1973].

The absence of a methodological approach, justification for chosing data categories and acceptable mathematical tests resulting in statistically significant quantifiable results, has led to incomplete results and subjectively interpreted conclusions.

II. STATEMENT OF PROBLEM

The primary objective of the thesis was to establish the basis for a statistical validation of the Theory of Biorhythms. It can be assumed that the general lack of acceptance and understanding of the theory is the cause of the difficulty to locate literature on the subject. The literature available is scarce and the subject matter is treated subjectively; consequently, a statistical analysis, in depth, would require careful interpretation of the theory. The theory has not been explicitly stated in detail in any of the literature while conflicting assumptions supporting each version of the theory depend upon the author. One problem area has been determining what a biorhythm actually measures. Willis' [1972] interpretation suggests that biorhythms are indicators of an individual's relative degree of potential performance capacity for a given time frame. Other potential problem areas include the interpretation of different biorhythm interactions when analyzing observed phenomena and proper classification of events as either physical, emotional, or intellectual. For example, Thommen [1973] classifies agility as an intellectual event while Willis implies that it is a physical event. Improper classification results in erroneous conclusions. It is often the case that emotional interactions contribute heavily to outcomes of athletic contests, consequently, athletic contests can not be analyzed strictly as a physical event. Most of the

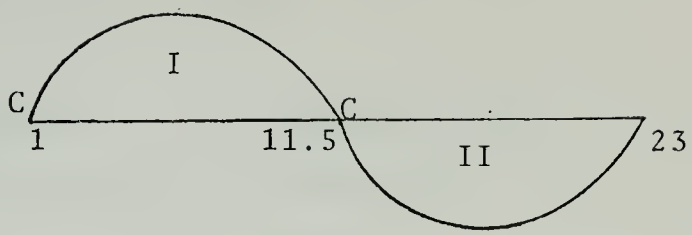
literature available consists of short interpretations of biorhythms and attempts to draw conclusions about the theory based upon subjective correlations between biorhythmic predictions and special cases of actual observed phenomena. The lack of a strong statistical foundation is one major stumbling block to universal acceptance of the Theory of Biorhythms. Statistical validation of the theory could possibly lead to revolutionary achievements in education, athletic strategies, and industrial safety.

III. INTERPRETATION OF THE THEORY OF BIORHYTHMS

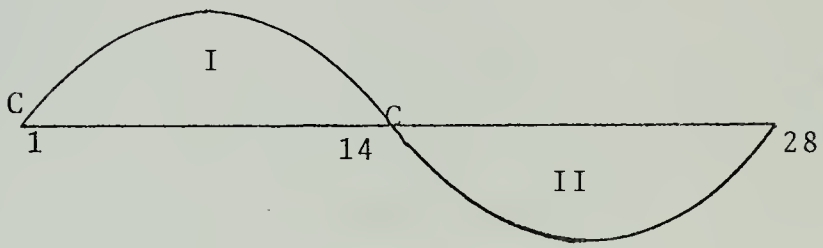
Human behavior is characterized by three inherent cycles called biological rhythms (biorhythms) which include a 23-day physical biorhythm, 28-day emotional biorhythm, and a 33-day intellectual biorhythm. Each biorhythm represents the individual's relative degree of potential performance capacity. It neither predicts what will happen in the future nor what happens in the present. Rather, biorhythms are indicators of the individual's physical, emotional, and intellectual performance capacity. In theory, it measures whether the potential capacity is greater than or less than some neutral standard on particular days within the cycle. That is, biorhythms measure the day to day variation in performance potential. The neutral standard represents the individual's neutral or average performance potential and is different for different individuals. A realization of performance potential occurs when a subject encounters a challenging situation. A challenge allows him to identify his full potential. Average days are days on which the individual does not encounter challenging situations which require a display of emotional, intellectual, and/or physical potential. For this reason, the individual should be aware of the different catalysts that may trigger potential reactions capable of being measures by a biorhythm.

Figure 1 is a graphical interpretation of The Theory of Biorhythms.

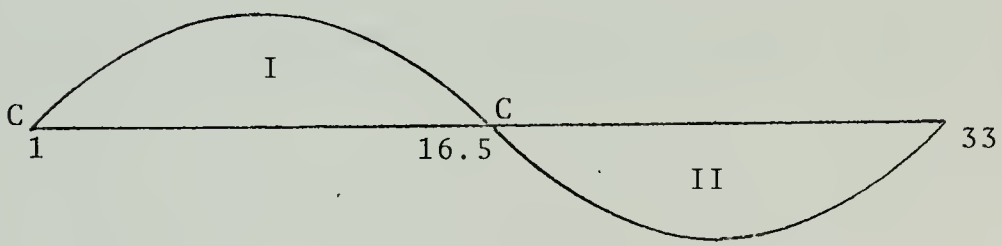
Physical Biorhythm



Emotional Biorhythm



Intellectual Biorhythm



C = Critical Days = A day on which the individual's potential capacity is considered unstable. On critical days, it is hypothesized that individuals can either have an extraordinary increase in performance or an extraordinary decrease in performance.

I = Good Performance Days = Days on which there is a greater potential for above average performance. These days occur within the first ½ cycle.

II = Poor Performance Days - Days on which there is a greater potential for below average performance. These days occur within the second ½ cycle.

Average Performance Day = A day on which the individual has not encountered a challenging situation. Average days can occur anywhere within the cycle.

Figure 1. Graphical Illustration of Biorhythms.

Thommen [1973] suggests the following subcategories are contained in each cycle.

Physical Cycle	Emotional Cycle	Intellectual Cycle
physical strength	sensibility	intelligence
endurance	nerves	memory
energy	feelings	mental alertness
resistance	intuition	logic
confidence	cheerfulness	reasoning power
	moodiness	reaction
	creative ability	agility
		ambition

Table I. Subcategories of Each Biorhythmic Cycle.

IV. SELECTION OF THE STATISTICAL MODEL

Although a variety of the statistical techniques available can be used to investigate biorhythm theory, model selection is dictated by characteristics of the data, as well as the appropriateness and quality of the model.

A. CHARACTERISTICS OF THE DATA

Three approaches are available. The first approach consists of collecting data resulting from a phenomena which is predictable from biorhythm theory and then selecting a statistical technique whose assumptions are satisfied by the data and whose results most appropriately illustrate the validity of the theory of biorhythms. In using this approach it should be obvious that the choice of the technique is influenced by the characteristics of the data, which must conform to the assumptions of the statistical model. For example, the most common assumption of parametric tests is homogeneity of sampling units. Although it may be possible to restore homogeneity through transgeneration, the use of non-homogenous data in a parametric test leads to invalid results. Consequently, the absence of proper data, which can force the use of a less appropriate statistical test, may result in inconclusive evidence supporting the theory.

The second approach consists of selecting the most appropriate statistical tests which best illustrate the validity of the biorhythm theory, then collect data conforming to the assumptions of that test.

A third approach was considered out of necessity. Data was often difficult to obtain which both illustrated particular aspects of the theory and conformed to the assumptions of the chosen statistical model. Consequently, it was necessary to transgenerate raw data into categorical variables and then proceed with a non-parametric test.

B. APPROPRIATENESS OF STATISTICAL MODEL

Appropriateness of the statistical test is determined by the objective of the thesis. Various parametric and non-parametric tests were considered. The robust t-test analysis of the variance, and their non-parametric counterparts would have been inappropriate since they allowed analysis of only specific segments of the cycle. Consequently, even if the results were favorable, the evidence would be inconclusive. For example, depending upon homogeneity qualities of the data, analysis of the variance could have been used to compare the statistical differences between biorhythmically predictable critical days and the actually observed critical days. However, this technique would not allow a simultaneous investigation of the statistical significance of the occurrence of other categorical events between the biorhythmic critical days. The results of the statistical models must completely support the objective of the thesis. Therefore, tests which offer only a partial analysis were considered inappropriate.

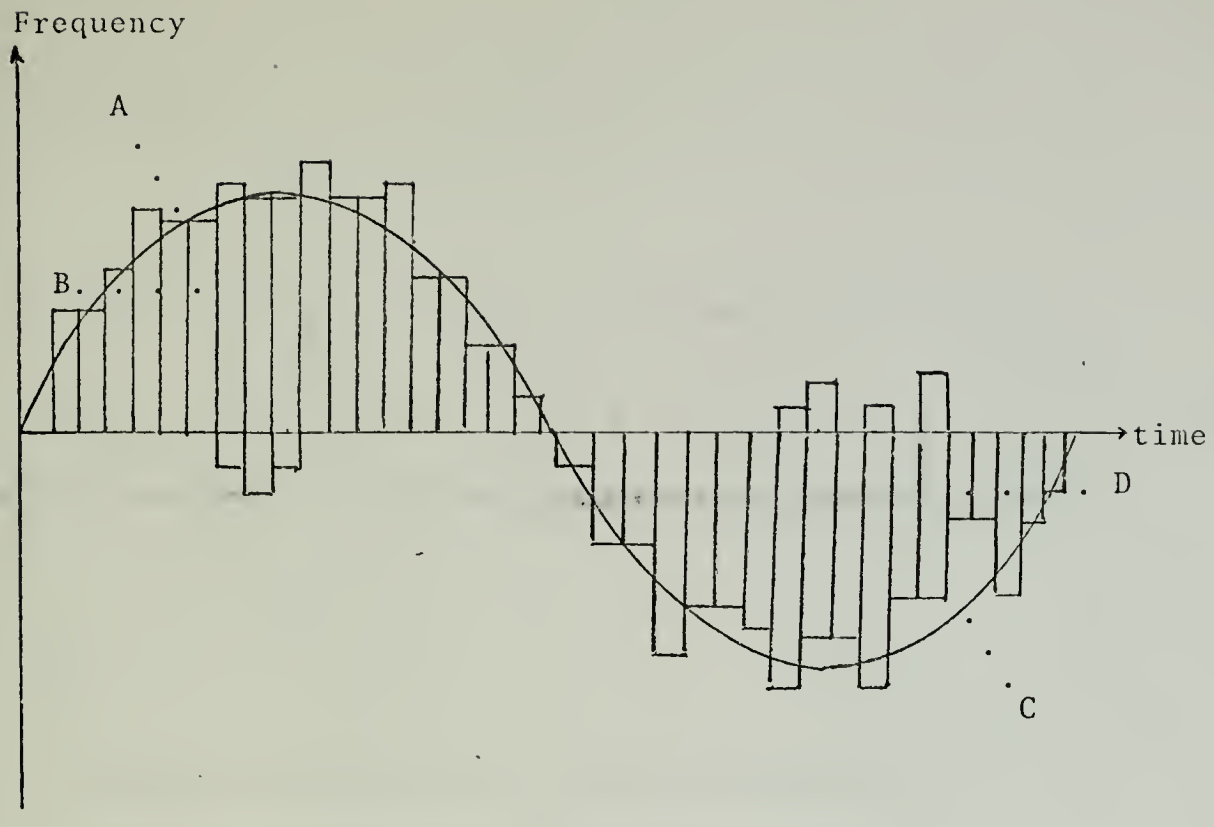
An appropriate statistical model for testing the validity of biorhythms should test the existence of a relationship or

dependency between observed good performance days and biorhythmically predictable good performance days and observed poor performance days and biorhythmically predictable poor performance days. Figure 2 illustrates this relationship.

It is intuitively appealling that a relationship exists since most of the good performance days occur during the first ½ cycle and most poor performance days occur during the second ½ cycle. An appropriate statistical model should be able to determine the presence of a relationship or dependency between theoretically predictable days and observed days as illustrated. If the occurrence of good days and poor days are equally likely to occur anywhere within the entire cycle then the distribution of these days should be uniform. Figure 3 illustrates this. A second statistical test should illustrate uniformity or non-uniformity. If the distribution is not uniform, this test should be able to identify the distributional form. Consequently, another statistical model should be used to illustrate uniformity or non-uniformity.

C. QUALITY OF STATISTICAL MODEL

When alternative statistical models are equally appropriate, the technique with greater quality is chosen. Although there may be various ways to determine the quality of a model, the most objective measure of quality is power-efficiency. Suppose two tests, A and B are equally appropriate. If test A requires N_a samples to have the same power as test B has with N_b samples then test B has



A = Theoretical envelope of biorhythmically predictable good days;

B = Hypothetical distribution of observed good days;

C = Theoretical envelope of biorhythmically predictable poor days;

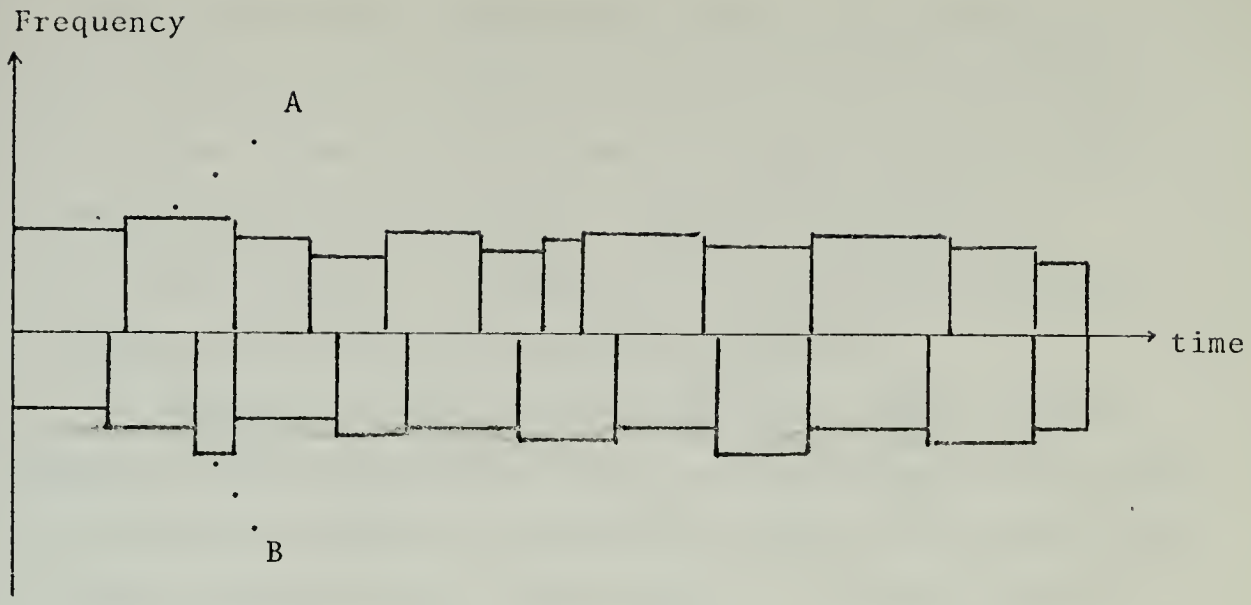
D = Hypothetical distribution of observed poor days.

Figure 2. Theoretical Biorhythm Superimposed Upon Hypothetical Distribution of Observed Good and Poor Performance Days.

$$\text{POWER-EFFICIENCY} = (100)\left(\frac{N_a}{N_b}\right)\%$$

where power is defined as the probability of rejecting the null hypothesis when it is false [Siegel, 1956].

Considering the characteristics of the data available, and appropriateness and quality of the statistical models, the Chi-Square Contingency Test for independence of criteria



A = Uniform distribution of observed good days;

B = Uniform distribution of observed poor days.

Figure 3. Hypothetical Sample from a Uniform Distribution of Good and Poor Performance Days.

and the Chi-Square Goodness-of-Fit-Test for distributional form were chosen as primary statistical techniques. Secondary techniques are available to give supporting evidence. When sample size is so small that the Chi-Square Contingency Test's expected value criterion does not hold, the Fischer Test for exact probability (without Tocher's modification) should be used. When the Chi-Square Goodness-of-Fit-Test's expected value criterion does not hold and category combination reduces the degrees of freedom to an undesirable level the Kolmorgorov-Smirnov Test for distributional form should be used.

These statistical techniques indicate the presence or lack of presence of a relationship and define the distributional form. They do not attempt to explain why the relationship is or is not present. Elaborate linear and curvilinear regression techniques are available for the development of quantitative explanatory models.

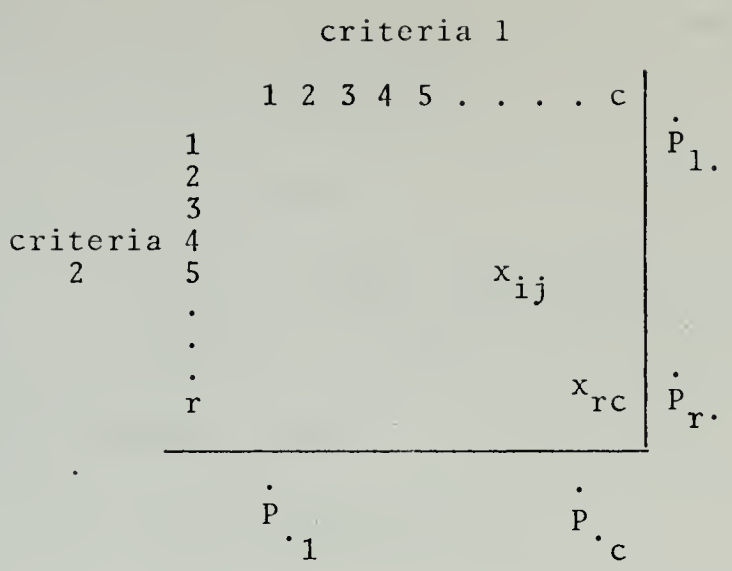
In addition to analyzing the data with respect to dependency and distributional form, it would also be desirable to measure the degree of correlation between the theoretical biorhythm and the actual observations. This can be most easily accomplished by utilizing the Chi-Square Contingency Coefficient.

D. CHI-SQUARE CONTINGENCY TEST

1. Theory

A two-way Chi-Square Contingency Test was used to illustrate the dependency between the day of occurrence of the observed event and the sequential day of the cycle. Biorhythm theory states that an individual's capacity to perform is dependent upon the sequential day of the cycle. Specifically, there is a greater capacity for an individual to excel during the first half cycle and a reduction in capacity during the last half of the cycle. Therefore, the Chi-Square Contingency Test was used to investigate the dependency between the day of occurrence of observed human performance and the sequential day of the cycle.

a. Data is arranged in the following tableau:



b. Given a sample of n observations.

c. Each observation can be classified according to two different criteria. One criteria has c levels with $c \geq 2$ and the other criteria has r levels with $r \geq 2$.

d. $\sum_{j=1}^{c} \sum_{i=1}^{r} x_{ij} = n.$

e. $\sum_{j=1}^{c} \sum_{i=1}^{r} P_{ij} = 1.$

f. $nP_{ij} \geq 5.$

g. Let x_{ij} be the number of observations which fall into class i criteria one and class j criteria two.

h. Let P_{ij} be the probability that an observation falls into class i criteria one and class j criteria two.

i. $P_{i.} = \frac{x_{i.}}{n}$ where $x_{i.} = \sum_{j=1}^{c} x_{ij}$.

j. $P_{.j} = \frac{x_{.j}}{n}$ where $x_{.j} = \sum_{i=1}^{r} x_{ij}$

k. $H_o : P_{ij} = (P_{i.})(P_{.j})$ for all i and j

$H_1 : P_{ij} \neq (P_{i.})(P_{.j})$.

1. If H_o is true:

$$V = \sum_{j=1}^{c} \sum_{i=1}^{r} \frac{(x_{ij} - nP_{i.}P_{.j})^2}{nP_{i.}P_{.j}} = \chi^2(r-1)(c-1)^{(1-\alpha)}.$$

m. Reject H_o if:

$$V > \chi^2(r-1)(c-1)^{(1-\alpha)}.$$

2. Procedure for the Application to the Theory of Biorhythms

a. Data tableau

Criteria 1

Criteria 2	Observed Good Days	Observed Bad Days
1^{st} ½ Cycle	x_{11}	x_{12}
2^{nd} ½ Cycle	x_{21}	x_{22}

1^{st} ½ cycle: represents biorhythmically predictable good performance days

2^{nd} ½ cycle: represents biorhythmically predictable poor performance days.

b. x_{ij} represents the number of observations which are categorized by both criteria levels i and j. For example, x_{21} represents the number of observed good performance days

on which the individual's performance was above average, which occurred during the second half of the cycle.

Figure 4 is a graphical illustration of x_{11}, x_{12}, x_{21}, and x_{22}.

c. $P_{i\cdot}$ and $P_{\cdot j}$ represent the maximum likelihood estimator for the probability that an observation is characterized by the respective criteria level. For example, $P_{1\cdot}$ represents the probability that a good or bad day occurs during the 1st half of the cycle.

d.

$$\dot{P}_{i\cdot} = \frac{x_{i\cdot}}{n} = \frac{\sum_{j=1}^{2} x_{ij}}{\sum_{j=1}^{2}\sum_{i=1}^{2} x_{ij}} \qquad \dot{P}_{\cdot j} = \frac{\sum_{i=1}^{2} x_{ij}}{\sum_{j=1}^{2}\sum_{i=1}^{2} x_{ij}}$$

$$\dot{P}_{1\cdot} = \frac{x_{11} + x_{12}}{x_{11} + x_{12} + x_{21} + x_{22}} \qquad \dot{P}_{\cdot 1} = \frac{x_{11} + x_{21}}{x_{11} + x_{12} + x_{21} + x_{22}}$$

$$\dot{P}_{2\cdot} = \frac{x_{21} + x_{22}}{x_{11} + x_{12} + x_{21} + x_{22}} \qquad \dot{P}_{\cdot 2} = \frac{x_{12} + x_{22}}{x_{11} + x_{12} + x_{21} + x_{22}}$$

e. For best results

$$E(x_{ij}) = nP_{i\cdot}P_{\cdot j} \geq 5.$$

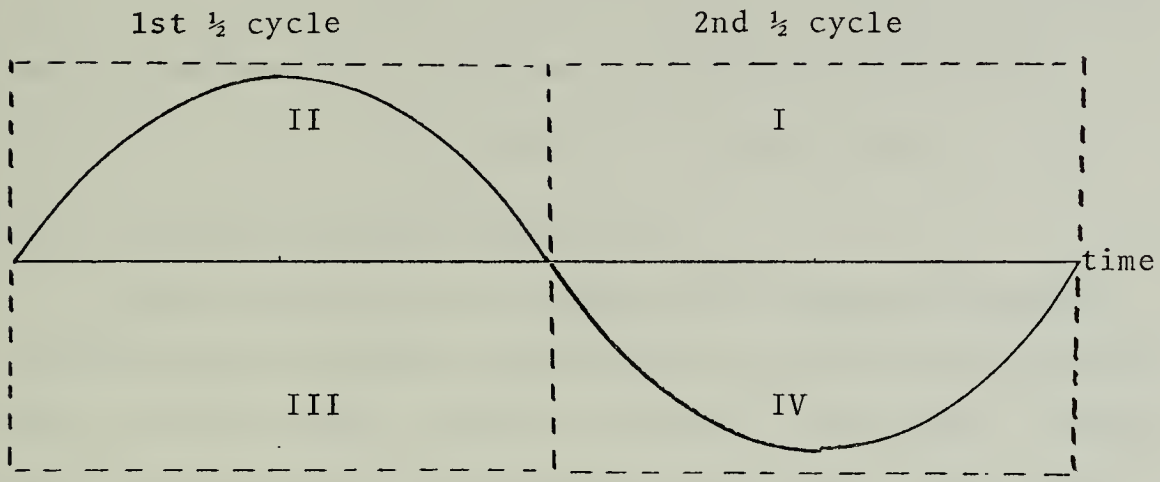
f. If H_o is true:

$$V = \sum_{j=1}^{2}\sum_{i=1}^{2} \frac{(x_{ij} - n\dot{P}_{i\cdot}\dot{P}_{\cdot j})^2}{n\dot{P}_{i\cdot}\dot{P}_{\cdot j}} = \chi^2(r-1)(c-1)^{(1-\alpha)}.$$

g. Reject H_o if:

$$V > \chi^2(r-1)(c-1)^{(1-\alpha)}.$$

Theoretical Biorhythm superimposed upon hypothetical distributions of observed good performance and poor performance days.



X_{11} = total number of observed good performance days occurring during the 1st ½ cycle. They appear in quadrant II.

X_{12} = total number of observed poor performance days occurring during the 1st ½ cycle. They appear in quadrant III.

X_{21} = total number of observed good performance days occurring during the 2nd ½ cycle. They appear in quadrant I.

X_{22} = total number of observed poor performance days occurring during the 2nd ½ cycle. They appear in quadrant IV.

Figure 4. Location of Statistical Data Within a Biorhythm.

E. CHI-SQUARE COEFFICIENT OF CONTINGENCY

The contingency coefficient is especially useful in that it measures the degree or strength of the relationship which was detected using the Chi-Square Contingency Test for dependence of criteria. It is calculated as follows.

$$C = \sqrt{\frac{\chi^2}{\chi^2 + N}}$$

C = Coefficient of Contingency.

χ^2 = Test statistic value (V) calculated from the Chi-Square Contingency Test (previously discussed).

N = Total number of observations.

F. CHI-SQUARE GOODNESS-OF-FIT TEST

If the occurrence of a categorical event was equally likely to occur anywhere within the cycle then the distribution of these events would be uniform. Consequently, validation of the theory of biorhythms necessitates illustrating that the occurrence of categorical events is not uniformly distributed. Investigating distributional form is most easily accomplished by utilizing the Chi-Square Goodness-of-Fit Test.

1. The data is organized in the following tableau.

Interval	Frequency	P_i	nP_i
$a \leq x < b$	Y_1	P_1	$E(Y_1)$
$b \leq x < c$	Y_2	P_2	$E(Y_2)$
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
$g \leq x \leq h$	Y_k	P_k	$E(Y_k)$

2. n: represents the sample size.

3. $a \leq x < b$: represents an interval of time.

4. Y_i: represents the frequency of occurrence of the observed phenomena within the i^{th} interval.

5. P_i: represents the probability that an observed event will occur, under the null hypothesis, during the associated interval.

6. nP_i: represents the expected number of observations within the i^{th} interval if the distribution of the frequency of occurrence of the phenomena conformed to the null hypothesis.

7. For most significant results $nP_i \geq 5$.

8. H_o : Hypothesized distributional form

   H_1 : The distribution is other than as hypothesized.

9. If H_o is true:

$$V = \sum_{i=1}^{k} \frac{(Y_i - nP_i)^2}{nP_i} = \chi^2(k-r-1)^{(1-\alpha)}.$$

   k-r-1 = degrees of freedom for the test statistic

   k = number of intervals

   r = number of estimators used in the hypothesized distribution.

10. Reject H_o if:

$$V > \chi^2(k-r-1)^{(1-\alpha)}.$$

11. In an application to biorhythms, the initial test is for the presence of a uniform distribution.

   H_o : the distribution is uniform.

   H_1 : the distribution is other than uniform

$$P_1 = \frac{b - a}{h - a}$$

$$P_2 = \frac{d - c}{h - a}$$

   .
   .
   .
   etc.

Acceptance of the Contingency Test's null hypothesis indicates that the day of occurrence of observed events is independent of the sequential day of the cycle. In other words, there is no relation between the days of occurrence of biorhythmically predictable events and the days of occurrence of the observed events. This is an indication that the distribution of the occurrence of sampled events should be uniform. It is considered conclusive evidence (statistically) that the Theory of Biorhythms is invalid, if for the same data, H_o for the Chi-Square Contingency Test and the Chi-Square Goodness-of-Fit Test is accepted. Rejection of both null hypotheses suggests validity of the theory. Further investigation of the distributional form would be desired. The presence of a known distributional form such as a normal or poisson would be a useful predictive device.

G. ESTIMATION OF PARAMETERS

Investigating the presence of more complex distributional forms usually results in estimating parameters of the hypothesized distribution. Consequently, estimators with good properties are important. The method of moments and the method of maximum likelihood techniques were considered.

1. Methods of Moments

a. Given a population random variable X is dependent upon k unknown parameters $\theta_1, \theta_2, \ldots, \theta_k$.

b. In general the first k population moments will depend upon these parameters (i.e., $E(X) = g(\theta_1, \theta_2, \ldots, \theta_k)$).

c. Equate the first k sample moments $M_1, M_2, \ldots, M_k$, to the first k population moments

$$M_k = \frac{1}{n} \sum_{i=1}^{n} (X_i)^k.$$

d. Solve for the desired parameter.

2. Method of Maximum Likelihood

a. Develop a likelihood function

$$L(\theta_1, \theta_2, \ldots, \theta_k) = \sum_{i=1}^{n} f_x(x).$$

b. Since $\sum_{i=1}^{n} f_x(x)$ is just another way of writing a sample's joint distribution function, the value of f(x) is actually a probability.

c. The idea of the MLE technique is to find the value of the unknown parameters within the joint density which will maximize it. This value maximizes the probability of occurrence. The procedure is as follows:

$$L(\theta) = \sum_{i=1}^{n} f_x(x)$$

$$K(\theta) = \ln(L(\theta))$$

$$\frac{d(K(\theta))}{d\theta} = \frac{d(\ln(L(\theta)))}{d\theta} = 0$$

solve for θ and label it $\hat{\theta}$.

In most cases the method of moments and the method of maximum likelihood yield the same results. However, in those cases for which the parameter estimators are different, the properties of the estimators should determine which

estimator will be used. In many cases it is desirable to have unbiased, consistent, estimators with the least variance and mean square error (MSE).

3. Bias

is an unbiased estimator for θ iff $E(\hat{\theta}) = 0$. The bias in is given by $b_{\hat{\theta}} = E(\hat{\theta}) - \theta$.

4. Consistency

is a consistent estimator for θ

iff $\lim_{n \to \infty} E(\hat{\theta}) = \theta$

$\lim_{n \to \infty} V(\hat{\theta}) = 0$.

5. Cramer Rao Lower Bounds

$$\sigma^2 = \frac{1}{nE[(\frac{\partial}{\partial\theta} \log f_X(x))^2]}$$

$$MSE = \frac{(1 + b'(\theta))^2}{nE[(\frac{\partial}{\partial\theta} \log f_X(x))^2]} .$$

Table II summarizes the combined statistical model suggested for testing the presence of a biorhythm.

H. CRITICALITY

Critical days are defined to be days on which an individual's potential capacity for performance is unstable. If an individual encounters a challenging situation on a biorhythmically critical day then it is possible that he will either have extreme negative potential or extreme positive potential. For example, it has been suggested that heart

	Statistical Model	Application
1.	χ^2 Contingency Test (Use Fischer Test for small samples)	Tests for the presence of a relationship between the different levels of performance and the days on which they occurred.
2.	χ^2 Coefficient of Contingency	Tests the strength of the relationship detected in step #1.
3.	χ^2 Goodness-of-Fit Test (Use Kolmogornov-Smirnov Test for small samples)	1st Application: Test for uniformity (test for the presence of cyclic phenomena). 2nd Application: Test for hypothesized distributional form. This allows the analyst to investigate the following: a) Form of cyclic phenomena b) Periodicity c) Frequency d) Criticalities

Note:

Tests should be applied in the above order.
Detailed discussion and application procedures for the Fischer Exact probability Test and the Kolmogornov-Smirnov Test for distributional form can be found in Siegel [1956].

Table II. Combined Statistical Model for Testing the Presence of a Biorhythm.

attack victims encountered their attacks on critical days. It is obvious that a heart attack can be classified as a critical event. However, did a statistically significant number of heart attack victims experience their heart attacks on biorhythmic critical days? Thus, criticality becomes an important factor when investigating the theory. For this reason, probabilistic arguments have been formulated for use in the following statistical model presented for investigating the significance of an event occurring on a critical day.

1. Definitions

Single Criticality = day on which only one biorhythm crosses the time axis.

Double Criticality = days on which any two biorhythms intersect while crossing the time axis.

Triple Criticality = day on which all three biorhythms intersect while crossing the time axis.

P(PCD) = probability that a physical critical day occurs by chance.

P(ECD) = probability that an emotional critical day occurs by chance.

P(ICD) = probability that an intellectual critical day occurs by chance.

P(PCDxECD) = probability that a double critical day occurs by chance where the intersecting biorhythms are physical and emotional.

P(PCDxICD) = probability that a double critical day occurs by chance where the intersecting biorhythms are physical and intellectual.

P(ECDxICD) = probability that a double critical day occurs by chance where the intersecting biorhythms are emotional and intellectual.

P(PCDxECDxICD) = probability that a triple critical day occurs by chance.

It is possible that there are differing degrees of double criticalities. For example, it may be that a physical x emotional double critical day possesses a higher degree of criticality than does a physical x intellectual double critical day.

2. Occurrence of Critical Days

The following table illustrates the frequency of occurrence, in days of all types of critical days.

Criticality	Biorhythm	Frequency (days)
Single	Physical (P)	11.50
Single	Emotional (E)	14.00
Single	Intellectual (I)	16.50
Double	P x E	161.00
Double	P x I	189.75
Double	E x I	231.00
Triple	P x E x I	2656.50

Table III. Frequency of Occurrence of Criticalities.

The frequency (days) is based upon the respective cycle length. For example, a single criticality for a physical biorhythm occurs every 11½ days. Since the physical biorhythm is hypothesized to be a 23-day sinusoid, it crosses the axis every 11½ days (i.e., 23/2 = 11½).

If the events are equally likely (uniform) to occur at any point in time, then the following probabilities measure the likelihood that the observed event will occur on the given biorhythmic critical day. Calculation was based on the frequency of occurrence of critical days and consideration was given to the uncertainity of birth data.

Chance Probability	0 Hr Variance	± 6 Hr Variance	± 12 Hr Variance
P(PCD)	.0869	.1304	.1739
P(ECD)	.0714	.1071	.1428
P(ICD)	.0606	.0909	.1212
P(PCD x ECD)	.0062	.0093	.0124
P(PCD x ICD)	.0053	.0078	.0105
P(ECD x ICD)	.0043	.0065	.0086
P(PCD x ECD x ICD)	.00037	.0005	.0007

Table IV. Chance Probability of Occurrence of Criticalities.

3. Selection of Statistical Model for Criticality

Biorhythm data is naturally dichotomous into those days on which critical events occurred and those days on which critical events did not occur. Since an important question to be answered in validating the concept of criticality would be; "Are the number of observed critical days statistically significantly greater than the number that would be expected if critical event days were to have occurred by pure chance?"; the binomial model was chosen.

4. Binomial Model

Assume X~Binomial (n,p)

H_o: P = *P(critical day occurs by chance)

H_1: P > P(critical day occurs by chance)

α : Level of significance

*Select appropriate probability from chance probability table.

Suppose that x observations out of n possible observations are classified as critical events.

Define $P(X \leq x)$ = probability that at most x critical events could have occurred by chance.

$$P(X \leq x) = \sum_{i=0}^{n} \binom{n}{i} P^i (1-P)^{n-i}$$

Decision: If $P < \alpha$ reject H_o in favor of H_1.

The decision to reject H_o says that the number of critical events which have occurred is significant.

For $n > 25$ it is suggested that a normal approximation to the above probability be used.

$$P(X \leq x) = \phi\left(\frac{(x \pm .5) - nP}{\sqrt{nP(1-P)}}\right).$$

Additional information:

$E(X)$ = expected number of critical events under H_o = nP.

$V(X)$ = variance of critical events under H_o = $nP(1-P)$.

The Binomial Model is primarily used when investigating the significance of single criticalities. The Multinomial Model should be used when investigating the statistical significance of data which contains single, double, and/or triple criticalities.

5. Multinomial Model

Suppose that N observed events are partitioned into S mutually exclusive events $A_1, A_2, \ldots, A_s$ with respective

probabilities of occurrence $P_1, P_2, \ldots, P_s$ such that $A_1 + A_2 + \ldots + A_s = N$ and $P_1 + P_2 + \ldots + P_s = 1$. Then $P(A_1$ occurs k_1 times; A_2 occurs k_2 times; ...; A_s occurs k_s times) is equal to

$$\binom{N}{k_1, k_2, k_3, \ldots, k_s} p_1^{k_1} p_2^{k_2} p_3^{k_3} \ldots p_s^{k_s}$$

I. BIORHYTHM ALGORITHM

1. Note the date (month-day-year) of the observed event.

2. Calculate the subject's age in days, from the subject's birth date up to and including the date of the observed event. The calculation must include regular leap year and centurial leap year considerations.

3. Let

A = subject's age in days,

CL = cycle length = 23 days for physical cycle
28 days for emotional cycle
33 days for intellectual cycle

CC = whole number of completed cycles
(whole number associated with A/CL)

SD = the day of the current biorhythm cycle on which the observed event occurred.

$$SD = \left(\frac{A}{CL} - CC\right)(CL).$$

J. DATA COLLECTION

Statistical validation of the theory necessitates performing two complete statistical analyses. The first analysis should use empirical data collected in a laboratory environment, for each subcategory. Experimental design should screen

out as much exterior influences and as much interaction as possible, from the subcategorical data being collected. The second analysis should utilize actual field data. It is here that cycle interaction will have to be assessed. For example, if the analyst chooses to gather bowling data for physical field data, he should be aware that there exists some degree of emotional and intellectual interaction. If the analyst chooses to analyze academic test scores, he should be aware of which tests challenged the subject's intellect, and that the importance of the test and the length of the test (i.e., time) will cause emotional and physical interaction respectively.

Since human behavior is extremely complex, there are a multitude of influencing factors. Therefore, it should be understood that biorhythms are not 'cure-alls'. A biorhythm is hypothesized to be merely one very small indicator of the variation of performance potential. The many influencing factors can easily contaminate biorhythmic analysis. Consequently, it is not expected that field data will yield as strong a statistical significance as experimental data.

V. ANALYSIS OF DATA

A. ANALYSIS OF INTELLECTUAL DATA

Four graduate students at the Naval Postgraduate School were chosen as subjects for investigation of intellectual biorhythms. Academic grades from 15 courses measured over a 14 month period provided 115 data points for analysis. Each student, pursuing his Master's Degree in Operations Research, was evaluated with respect to the same courses. To eliminate a degree of subjectivity, only mathematically oriented courses were used. It was believed that grades were arrived at more objectively and that the subject's identification of his own neutral, average performance would be more accurate. Identification of this average performance is considered critical since it allows the analyst to categorize those performances which were above and those performances which were below average. Table V summarizes the data base.

The data was next arranged in the Intellectual Data Tableau which is shown as Table VI.

1. Tests for the Presence of an Intellectual Biorhythm

a. χ^2 Contingency Test

H_o: Observed good performance days and observed poor performance days are independent of where they occur within the intellectual biorhythm.

H_1: Observed good performance days and observed poor performance days are dependent of where they occur within the intellectual biorhythm.

Subject #1

Course Code	Date of Exam	Grade Ach/Grade Poss	Day of Current Intellect Cycle	Ranking of Performance Potential
MC	12 Oct 72	90/100	18	0
	20 Nov 72	38/ 50	24	-
	11 Dec 72	90/100	12	++
PH(I)	20 Oct 72	90/100	26	0
	21 Nov 72	82/100	25	0
	12 Dec 72	80/100	13	0
OA	13 Dec 72	93/100	14	+
P(I)	11 Dec 72	88/100	12	++
	05 Oct 72	5/ 10	11	-
	19 Oct 72	6/ 10	25	-
	02 Nov 72	9/ 10	06	++
	16 Nov 72	7/ 10	20	0
	30 Nov 72	8/ 10	01	+
PH(II)	29 Jan 73	50/100	28	-
	26 Feb 73	74/100	23	0
	21 Mar 73	86/100	13	++
P(II)	24 Jan 73	24/ 50	23	-
	14 Feb 73	35/ 50	11	+
	19 Mar 73	26/ 50	11	+
LA(I)	13 Jan 73	91/100	12	++
	22 Jan 73	93/100	21	++
	01 Feb 73	84/100	31	0
	12 Feb 73	88/100	09	+
LA(II)	05 Mar 73	78/100	30	--
	13 Mar 73	100/100	05	+
	20 Mar 73	93/100	12	++
ECON(I)	25 Apr 73	59/100	15	0
	29 May 73	78/100	16	Ø
	12 Jun 73	56/100	30	-

Table V. Intellectual Biorhythm Data Base.

Table V. continued

Course Code	Date of Exam	Grade Ach/Grade Poss	Day of Current Intellect Cycle	Ranking of Performance Potential
Subject #1				
P(III)	19 Apr 73	21/ 50	07	-
	21 May 73	42/ 50	08	+
	12 Jun 73	82/100	30	0
HF	03 May 73	91/100	23	0
	11 Jun 73	90/100	29	0
LP	17 Apr 73	48/ 50	07	++
	13 Jun 73	58/100	31	--
STOCH(I)	16 Aug 73	80/100	29	0
	18 Sep 73	80/100	29	-
SS	08 Aug 73	85/100	21	-
ECON(II)	07 Aug 73	56/100	20	-
Subject #2				
P(III)	19 Apr 73		21	-
	21 May 73		20	-
	12 Jun 73		09	+
HF	03 May 73		02	+
	11 Jun 73		08	+
LP	13 Jun 73		10	0
STOCH(I)	16 Aug 73		08	0
	18 Sep 73		08	+
ECON(II)	07 Aug 73		32	-

Table V. continued

Subject #3

Course Code	Date of Exam	Grade Ach/Grade Poss	Day of Current Intellect Cycle	Ranking of Performance Potential
MC	12 Oct 72	72/100	00	-
	20 Nov 72	36/ 50	06	+
	11 Dec 72	94/100	27	-
PH(I)	20 Oct 72	75/100	08	0
	21 Nov 72	78/100	07	+
PROB(I)	11 Dec 72		27	-
	05 Oct 72		26	-
	19 Oct 72		07	0
	02 Nov 72		21	-
	16 Nov 72		02	0
	30 Nov 72		16	++
PH(II)	29 Jan 73	45/100	10	-
	26 Feb 73	70/100	05	++
	21 Mar 73		28	+
P(II)	24 Jan 73	26/ 50	05	+
	14 Feb 73	20/ 50	26	-
	19 Mar 73	25/ 50	26	0
LA(I)	12 Feb 73		24	+
LA(II)	20 Mar 73		27	--
ECON(II)	07 Aug 73		02	+
ECON(I)	25 Apr 73	45/100	30	-
	29 May 73		31	0
	12 Jun 73		12	-
SS	08 Aug 73		03	+
P(III)	19 Apr 73	14/ 50	24	-
	12 Jun 73	55/100	12	-
	21 May 73	36/100	23	+
HF	11 Jun 73	89/100	11	+
	03 May 73	85/100	05	+
LP	13 Jun 73	59/100	13	-
	17 Apr 73	46/ 50	18	+
STOCH(I)	16 Aug 73	80/100	11	+
	18 Sep 73	65/100	11	-

Table V. continued

Subject #4

Course Code	Date of Exam	Grade Ach/Grade Poss	Day of Current Intellect Cycle	Ranking of Performance Potential
MC	12 Oct 72	72/100	25	0
	20 Nov 72	34/ 50	31	-
	11 Dec 72	92/100	19	-
PH(I)	20 Oct 72	Poor	00	-
	21 Nov 72	65/100	32	0
	12 Dec 72	80/100	20	+
OA	13 Dec 72		21	-
P(I)	11 Dec 72	60/100	19	-
	05 Oct 72	02/ 10	18	--
	19 Oct 72	03/ 10	32	-
	02 Nov 72		13	0
	16 Nov 72		27	0
	30 Nov 72		08	0
PH(II)	21 Mar 73	88/100	20	+
ECON(I)	25 Apr 73	68/100	22	+
	29 May 73		23	-
	12 Jun 73		04	++
P(III)	19 Apr 73	14/100	16	-
	21 May 73	40/ 50	15	+
	12 Jun 73	78/100	04	++
HF	03 May 73	86/100	30	+
	11 Jun 73	90/100	20	+
LP	17 Apr 73	48/ 50	14	++
STOCH(I)	16 Aug 73	80/100	03	++
	18 Sep 73	50/100	05	--
SS	08 Aug 73	85/100	28	0
ECON(II)	07 Aug 73		27	-
P(II)	05 Feb 73	22/100	09	--
	02 Mar 73	62/100	01	++
	19 Mar 73	21/100	18	-

Table V. continued

Subject #4

Course Code	Date of Exam	Grade Ach/Grade Poss	Day of Current Intellect Cycle	Ranking of Performance Potential
LA	29 Jan 73	85/100	02	+
	12 Feb 73		16	-
	07 Mar 73	84/100	06	+
	20 Mar 73		19	-

KEY

MC = Multivariable Calculus
PH = Physics
OA = Operations Analysis
P = Probability
LA = Linear Algebra
LP = Linear Programming
HF = Human Factors
SS = Systems Simulation
ECON = Mathematical Economics
STOCH = Stochastic Models

0 = average performance
+ = slightly above average performance
++ = well above average performance
- = slightly below average performance
-- = well below average performance
Ø = critical performance

The scale was based upon how the subject's numerical performance ranked relative to his own overall average as well as the class average for that particular exam. Suppose, for example, that subject #1 scored 90 points out of a possible 100 points on a Multivariable Calculus exam. If the class average was 75 and the subjects overall average at the time of the exam was 80, then he was ranked ++. Since many ranking scales used in the academic community are ordinal, at best, the choice between + and ++ is subjective.

Cycle Day	Avg Per 0	Slightly Above Avg (+)	Well Above Avg (++)	Slightly Below Avg (-)	Well Below Avg (--)	Critical Ø
1		1	1	2		
2	1	3				
3		1	1			
4			2			
5		3	1		1	
6		2	1			
7	1	1	1	1		
8	3	3				
9		2			1	
10	1			1		
11		4		2		
12			4	2		
13	2		1	1		
14		1	1			
15	1	1	1			
16				2		1
17						
18	1	1		1	1	
19				2		
20	1	3		3		
21			1	3		
22		1				
23	2	1		2		
24		1		2		
25	2			1		
26	2			2		
27	1			3	1	
28	1	1		1		
29	2			1		
30	1	1		2	1	
31	2			1	1	
32	1			2		
33						

1. The data points within the tableau represent the frequency of occurrence. For example, there were four above average performances on the 11th day of the cycle.

2. The data can now be easily categorized for use in the various statistical models.

Table VI. Intellectual Data Tableau.

α : Level of Significance = .005.

	Observed Good Performance Days	Observed Poor Performance Days
1st ¼ Cycle	21	4
2nd ¼ Cycle	15	9
3rd ¼ Cycle	8	14
4th ¼ Cycle	2	16

$\chi^2_3(.995) = 12.8 \quad V = 25.7$

Table VII. Intellectual Data χ^2 Contingency Test.

Decision: Reject H_o in favor of H_1. This indicates the presence of a relationship between the different levels of performance and the biorhythmic days on which they occurred.

b. χ^2 Coefficient of Contingency

$$C = \sqrt{\frac{N}{V + N}} = \sqrt{\frac{25.7}{25.7 + 89}} = .48.$$

This represents the strength of the relationship. It is important to realize that C = .48 indicates that the relationship is strong. Notice that even if the relationship were perfect, it would be impossible for C = 1, since V/V + N will always be less than 1.

2. Distribution of Average Performance Days

a. Test For Uniformity

χ^2 Goodness-of-Fit Test

H_o: The distribution of average performance days is uniformly distributed over the intellectual biorhythm.

H_1: The distribution of average performance days is not uniformly distributed over the intellectual biorhythm.

α : Level of Significance = .01.

Interval (days)	Frequency	$\dot{P}_i$	$n\dot{P}_i$
$1 \leq t \leq 8$	5	8/33	6.06
$8 < t \leq 16$	4	8/33	6.06
$16 < t \leq 26$	8	10/33	7.57
$26 < t \leq 33$	8	7/33	5.30

$\chi^2_3(.99) = 11.3$ $\quad V = 2.28.$

Table VIII. Intellectual Data (Average Performance Days): χ^2 Goodness-of-Fit Test for Uniformity.

Decision: Do not reject H_o.

Kolmogorov-Smirnov Test

Utilizing the same H_o, H_1, and α as above:

Interval	$1 \leq t \leq 8$	$8 < t \leq 16$	$16 < t \leq 26$	$26 < t \leq 33$
Frequency	5	4	8	8
$F_o(x)$	8/33	16/33	26/33	33/33
$S_{25}(x)$	5/25	9/25	17/25	25/25
$\lvert F_o - S_{25} \rvert$	.0424	.1248	.1079	00.00

Critical D = .32 Calculated D = .1248.

Table IX. Intellectual Data (Average Performance Days): Kolmogorov-Smirnov Test for Uniformity.

Decision: Do not reject H_o.

Since the distribution is uniformly distributed, there is no need to further investigate distributional form.

The above analysis confirms the assumption that average performance days can occur anywhere within the cycle with equal probability (uniformity).

3. Distribution of Above Average Performance Days

For stronger test results, the slightly above average (+) and well above average (++) performance days were combined for analysis under the heading of above average performance days.

a. Test for Uniformity

χ^2 Goodness-of-Fit Test

H_o: The distribution of above average performance days is uniformly distributed over the intellectual biorhythm.

H_1: The distribution of above average performance days is not uniformly distributed over the intellectual biorhythm.

α : Level of Significance = .01.

Interval (days)	Frequency	$\dot{P}_i$	$n\dot{P}_i$
$1 \leq t \leq 5$	13	5/33	6.96
$5 < t \leq 10$	10	5/33	6.96
$10 < t \leq 15$	13	5/33	6.96
$15 < t < 20$	4	5/33	6.96
$20 < t \leq 25$	4	5/33	6.96
$25 < t \leq 33$	2	8/33	11.20

$\chi^2_5(.99) = 15.1$ $\quad V = 21.88.$

Table X. Intellectual Data (Above Average Performance Days): χ^2 Goodness-of-Fit Test for Uniformity.

Decision: Reject H_o in favor of H_1.

Kolmogorov-Smirnov Test

Utilizing the same H_o, H_1, and α as discussed previously:

Interval	$1 \leq t \leq 5$	$5 < t \leq 10$	$10 < t \leq 15$	$15 < t \leq 20$	$20 < t \leq 25$	$25 < t \leq 33$
Frequency	13	10	13	4	4	2
$F_o(x)$	5/33	10/33	15/33	20/33	25/33	33/33
$S_{46}(x)$	13/46	23/46	36/46	40/46	44/46	46/46
$\|F - S\|$	.1311	.1970	.3281	.2635	.3504	00.00

Critical D = .2403 Calculated D = .3504

Table XI. Intellectual Data (Above Average Performance Days): Kolmogorov-Smirnov Test for Uniformity.

Decision: Reject H_o in favor of H_1.

Both of the above tests tested for uniformity. Lack of uniformity suggests the presence of a cyclic phenomena.

b. Test for Distributional Form

χ^2 Goodness-of-Fit Test

H_o: The distributional form of above average performance days is N(8.5,5).

H_1: H_o is false.

α : Level of Significance = .01.

Interval (days)	Frequency	$\dot{P}_i$	$n\dot{P}_i$
$-\infty \leq t \leq 3$	7	.1357	6.24
$3 < t \leq 12$	24	.6226	28.64
$12 < t \leq \infty$	15	.2417	11.12

Table XII. Intellectual Data (Overall Above Average Performance Days): χ^2 Goodness-of-Fit Test for Distributional Form.

$\chi^2_2(.99) = 9.21$ V = 2.19

Decision: Do not reject H_o.

4. Distribution of Below Average Performance Days

For stronger test results the slightly below average (-) and well below average (--) performance days were combined for analysis under the heading of below average performance days.

a. Test for Uniformity

χ^2 Goodness-of-Fit Test

H_o: The distribution of below average performance days is uniformly distributed over the intellectual biorhythm.

H_1: The distribution of below average performance days is not uniformly distributed over the intellectual biorhythm.

α : Level of Significance = .10.

Interval (days)	Frequency	$\dot{P}_i$	$n\dot{P}_i$
$1 \leq t \leq 8$	4	8/33	10.42
$8 < t \leq 16$	9	8/33	10.42
$16 < t \leq 27$	21	11/33	14.34
$27 < t \leq 33$	9	6/33	7.82

$\chi^2_3(.90) = 6.25$ V = 7.42

Table XIII. Intellectual Data (Below Average Performance Days): χ^2 Goodness-of-Fit Test for Uniformity.

Decision: Reject H_o in favor of H_1.

Kolmogorov-Smirnov Test

Utilizing the same H_o, H_1, and α as previously discussed

Interval	$1 \leq t \leq 8$	$8 < t \leq 16$	$16 < t \leq 27$	$27 < t \leq 33$
Frequency	4	9	21	9
$F_o(x)$	8/33	16/33	27/33	33/33
$S_{43}(x)$	4/43	13/43	34/43	43/43
$F_o - S_{43}$	.1494	.1825	.0275	00.00

Critical D = .1753 Calculated D = .1825.

Table XIV. Intellectual Data (Below Average Performance Days): Kolmogorov-Smirnov Test for Uniformity.

Decision: Reject H_o.

b. Test for Distributional Form

χ^2 Goodness-of-Fit Test

H_o: The distributional form of below average performance days is $\beta(4,2)$

H_1: H_o is false.

α : Level of Significance = .01.

Interval (days)	Frequency	$\dot{P}_i$	$n\dot{P}_i$
$1 \leq t \leq 20$	13	.350	15.050
$20 < t \leq 30$	24	.575	24.725
$30 < t \leq 33$	6	.075	3.225

$\chi^2_2(.99) = 9.21$ V = 2.69.

Table XV. Intellectual Data (Overall Below Average Performance Days): χ^2 Goodness-of-Fit Test for Distributional Form.

Decision: Do not reject H_o.

B. ANALYSIS OF ACCIDENT DATA

Sixty-six accident claims from the Canadian Forest Products Ltd. (Howe Sound Pulp Division) were analyzed primarily with respect to their physical biorhythms. Those accidents analyzed were single victim accidents in which the accident was not believed to be caused or influenced by a second party. Table XVI summarizes the data base.

The data was next arranged in the Physical Biorhythm Data Base tableau which is shown as Table XVII.

1. Tests for the Presence of a Physical Biorhythm

a. First Analysis

Since accidents are considered in the below average performance category, the χ^2 Contingency Test and χ^2 Coefficient of Contingency are inappropriate. Consequently, the analysis begins with a test for uniformity.

χ^2 Goodness-of-Fit Test

H_o: The occurrence of accidents is uniformly distributed over the physical biorhythm.

H_1: The occurrence of accidents is not uniformly distributed over the physical biorhythm.

α : Level of Significance = .1.

Interval (days)	Frequency	$\dot{P}_i$	$n\dot{P}_i$
$1 \leq t \leq 5$	10	5/23	14.35
$5 < t \leq 10$	08	5/23	14.35
$10 < t \leq 15$	20	5/23	14.35
$15 < t \leq 20$	15	5/23	14.35
$20 < t \leq 23$	13	3/23	8.60

$\chi^2_4(.90) = 7.78$ V = 8.63

Table XVIII. Accident Data (1st Analysis): χ^2 Goodness-of-Fit Test for Uniformity.

Subject #	Day of Current Phys Biorhythm	Day of Current Emot Biorhythm	Day of Current Int Biorhythm
1	21	22	24
2	19	19	26
3	13	22	25
4	11	02	18
5	03	02	09
6	10	22	14
7	21	21	19
8	00	20	17
9	19	11	19
10	08	25	19
11	19	11	04
12	22	13	18
13	20	05	23
14	13	02	21
15	07	11	20
16	02	02	10
17	04	24	24
18	14	23	21
19	16	24	16
20	22	01	07
21	16	15	04
22	10	17	07
23	11	18	09
24	05	13	21
25	05	09	05
26	00	20	17
27	14	02	05
28	16	27	25
29	21	27	19
30	18	10	24
31	19	09	08
32	10	20	05
33	20	19	30
34	03	04	14
35	22	10	07
36	12	25	06
37	00	01	01
38	13	04	21
39	21	20	31
40	12	00	27
41	17	02	31
42	14	02	11
43	21	10	26
44	07	09	08
45	11	19	26

Table XVI. Accident Data Base.

Table XVI. continued

Subject #	Day of Current Phys Biorhythm	Day of Current Emot Biorhythm	Day of Current Int Biorhythm
46	20	11	01
47	14	17	24
48	02	03	24
49	21	09	17
50	19	11	32
51	01	15	16
52	15	10	28
53	17	09	04
54	15	23	04
55	00	18	24
56	11	15	16
57	13	01	07
58	15	11	17
59	17	26	06
60	09	14	15
61	07	15	12
62	14	25	15
63	01	16	07
64	01	09	04
65	13	18	31
66	14	04	20

Cycle Day	Accident Frequency
1	3
2	2
3	2
4	1
5	2
6	
7	3
8	1
9	1
10	3
11	4
12	2
13	5
14	6
15	3
16	3
17	3
18	1
19	5
20	3
21	6
22	3
00	4

Frequency refers to the total number of accidents which occurred on the respective biorhythm day. For example, of the 66 subjects, three experienced accidents on the first day of their physical biorhythm, two experienced their accidents on the second day, etc. The data can now be easily categorized for use in the various statistical models.

Table XVII. Physical Biorhythm Data Base.

Decision: Reject H_o in favor of H_1.

Kolmogorov-Smirnov Test

Utilizing the same H_o, H_1, and α as previously discussed

Interval (days)	$1 \leq t \leq 5$	$5 < t \leq 10$	$10 < t \leq 15$	$15 < t \leq 20$	$20 < t \leq 23$
Frequency	10	8	20	15	13
$F_o(x)$	5/23	10/23	15/23	20/23	23/23
$S_{66}(x)$	10/66	18/66	38/66	53/66	66/66
$F_o - S_{66}$	.0655	.1620	.0764	.0665	00.00

Critical D = .1502 Calculated D = .1620.

Table XIX. Accident Data (1st Analysis): Kolmogorov-Smirnov Test for Uniformity.

Decision: Reject H_o in favor of H_1.

Rejection of the uniformity hypothesis by both statistical tests suggests the presence of a cyclic phenomena.

b. Second Analysis

The Theory of Biorhythms has a built in variance of ±12 hours (24 hours) due to the uncertainty of the exact hour of birth. Consequently, it is possible that the original calculations may be as much as 24 hours away from where they appear in the original data tableau. This analysis investigates the statistical significance in shifting the data 24 hours (optimally).

χ^2 Goodness-of-Fit Test

H_o: The occurrence of accidents is uniformly distributed over the physical biorhythm.

Cycle Day	Accident Frequency
1	1
2	1
3	2
4	1
5	1
6	1
7	2
8	2
9	1
10	1
11	2
12	6
13	5
14	6
15	3
16	3
17	3
18	1
19	5
20	3
21	6
22	3
23	7

Table XX. Optimal Data Tableau.

H_1: The occurrence of accidents is not uniformly distributed over the physical biorhythm.

α : Level of Significance = .005.

Interval (days)	Frequency	$\dot{P}_i$	$n\dot{P}_i$
$1 \leq t \leq 5$	6	5/23	14.35
$5 < t \leq 10$	7	5/23	14.35
$10 < t \leq 15$	22	5/23	14.35
$15 < t \leq 20$	15	5/23	14.35
$20 \leq t \leq 23$	16	3/23	8.60

$\chi^2_4(.995) = 14.9$ $\quad V = 19.71.$

Table XXI. Accident Data (2nd Analysis): χ^2 Goodness-of-Fit Test for Uniformity.

Decision: Reject H_o in favor of H_1.

Kolmogorov-Smirnov Test

Utilizing the same H_o, H_1, and α as previously discussed

Interval	$1 \leq t \leq 5$	$5 < t \leq 10$	$10 < t \leq 15$	$15 < t \leq 20$	$20 < t \leq 23$
Frequency	6	7	22	15	16
$F_o(x)$	5/23	10/23	15/23	20/23	23/23
$S_{66}(x)$	6/66	13/66	35/66	50/66	66/66
$F_o - S_{66}$	.1265	.2378	.1219	.1120	00.00

Critical D = .2006 Calculated D = .2378

Table XXII. Accident Data (2nd Analysis); Kolmogorov-Smirnov Test for Uniformity.

Decision: Reject H_o.

The above analysis shows that shifting the occurrence within the cycle by 24 hours yields more significant results. However, knowledge of the subject's exact hour of birth eliminates the need for shifting the data 24 hours and yields more reliable results.

c. Third Analysis

This analysis dichotomizes the data into loss-time accidents and non-loss-time accidents. A loss-time accident is an accident which results in the employee remaining out of work for at least one day. The following tableau contains data from loss-time-accident subjects.

Subject #	Day of Current Phys Biorhythm	Day of Current Emot Biorhythm	Day of Current Int Biorhythm
01	*21	22	24
11	19	11	04
18	14	23	21
20	*22	*01	07
21	16	*15	04
23	*11	18	09
39	*21	20	*31
41	17	*02	*31
53	17	09	04
58	15	11	*17
66	14	04	20

*It is possible, assuming ±12 hours variance, that these days could have been critical days.

Table XXIII. Loss-Time Accidents.

χ^2 Contingency Test

H_o: Loss-time accidents and non-loss-time accidents independent of where they occur within the physical biorhythm.

H_1: Loss-time accidents and non-loss-time accidents are dependent of where they occur within the physical biorhythm.

α : Level of Significance = .05.

	Loss-Time Accidents	Non-Loss-Time Accidents
1st ½ Cycle	1	21
2nd ½ Cycle	11	33

$\chi^2_1(.95) = 3.84$ $V = 4.18$.

Table XXIV. χ^2 Contingency Test.

Decision: Reject H_o in favor of H_1.

This result illustrates more severe accidents are dependent upon the sequential day of the subjects' biorhythm.

χ^2 Coefficient of Contingency

$$C = \sqrt{\frac{V}{V + N}}$$

$$C = \sqrt{\frac{4.18}{4.18 + 66}}$$

$$C = .244.$$

This represents the degree of association or the strength of the relationship previously measured by the χ^2 Contingency Test. The Coefficient of Contingency is just another way of examining the strength of the rejection in the χ^2 Contingency Test. Had the χ^2 Contingency's null hypothesis (that of independence) has been rejected, there would have been no reason to calculate a Contingency Coefficient since the χ^2 deviation statistic would have been so small that the resulting Coefficient would have been insignificant. This can be illustrated by examining the formula. In order not to reject the null hypothesis, the deviation statistic would have to be less than 3.84. Assume that this statistic was 1.5. With the same sample size of 66, the Coefficient of Contingency is equal to .149 which is insignificant at any alpha level. A close examination of the parameters V and N illustrates that one must be careful when interpreting this coefficient. A plot of the Contingency Coefficient against sample size, holding the deviation constant

will show that as the sample size becomes large, the coefficient becomes asymptotic to zero. Consequently, it is more sensitive to smaller sample sizes, as is the case with this biorhythm data.

2. Criticality

Lack of data eliminates an indepth analysis of criticality, however, it is interesting to observe the occurrence of criticalities among loss-time accident victims.

Let

X = criticalities

P(PCD) = .1739

P(ECD) = .1428

P(ICD) = .1212.

Biorhythm	E(X)	V(X)	# Critical Observations
Physical	1.91	1.58	4
Emotional	1.57	1.35	3
Intellectual	1.33	1.16	3

Table XXV. Accident Data Criticality Tableau.

The following probabilities were calculated using the binomial model.

Let

X = # criticalities observed within a physical biorhythm out of 11 possible observations.

P(PCD) = .1739.

Table XXVI illustrates that the expected (mean) number of observed criticalities (1.91) occurs with highest probability while four or more criticalities can be considered

a rare event. Figure 5 illustrates that 90% of the probability of occurrence of critical observations is contained within 1.5 standard deviations of the mean.

n	P(X=n)
0	.123300000
1	.283109200
2	.297651200
3	.187889600
4	.077992200
5	.023344900
6	.004905300
7	.000722300
8	.000074400
9	.000003700
10	.000000158
11	.000000003

Table XXVI. Criticality Prob Tableau.

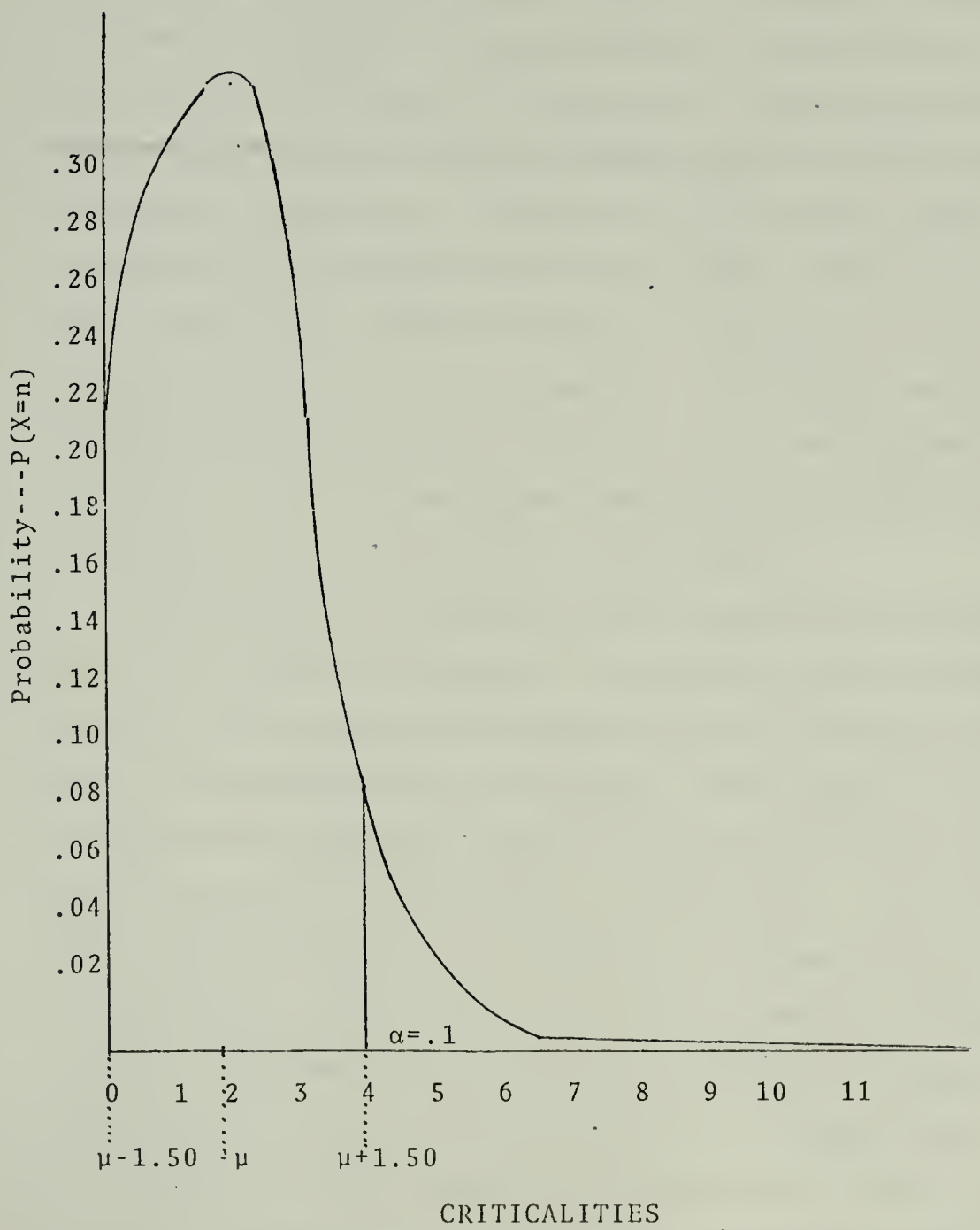


Figure 5. Observed Accident Data Density Function.

VI. DISCUSSION

Results based on statistical models are heavily dependent on the researcher's interpretation of the theory. One who considers criticality as the backbone of the theory will stress different aspects of biorhythmic analysis than will a researcher who believes criticality plays a minor role in biorhythmic prediction. Consequently, the choice and development of the combined statistical model illustrates that every aspect of a biorhythm should be analyzed prior to drawing conclusions. Use of the models in a thorough and rigid analysis would allow one to draw objective conclusions based on fact instead of formulating broad generalizations based on subjective interpretations of the theory.

The analysis of intellectual and accident data are not meant to validate the theory. The analyses both illustrate the use of the statistical models as well as support this paper's interpretation of biorhythms. The analysis of intellectual data rigidly adhered to the combined statistical model for testing the presence of a biorhythm. At the .005 level of significance the Chi-Square Contingency Test established that a relationship existed between the different levels of performance and the days on which they occurred. Supporting this result was an impressive .48 coefficient of contingency. As was expected the application of both the Chi-Square Goodness-of-Fit Test and the Kolmogorov-Smirnov Test (KS) to average performance data showed that days on

which the subject was not intellectually challenged (average performance days) were uniformly distributed over the entire cycle. This result is coincidental with biorhythm theory. Biorhythms measure variation in performance potential. On average days variation is zero and thus unpredictable and completely random as in the case of the uniform distribution. However, repeated application of the Chi-Square and KS Tests to the above and below average performance days illustrated non-uniformity which, according to the model implies a cyclic phenomena. Identification of the distribution of both the above and below average performance days was possible. Identifying the distribution is instrumental in that it allows one to determine expected frequencies and their variations. Although application of both statistical tests was not necessary, the use of the additional test serves as a check and lends supporting evidence to the original analysis. For small samples the KS Test is more powerful since the Chi-Square Test is forced to combine categories when expected value criteria are not met. It is realized that the limited sample size presents difficulties when attempting to dichotomize in attempts to gain as much information as possible from the data. However the significance of the results is impressive regardless of the sample size. The presence of only one critical event prevented a criticality analysis.

There are many problems encountered when attempting to analyze data such as academic grades. It has been the

author's experience that exams on the graduate level are designed to challenge the student. Most conscienious students over-prepare for exams thus reducing the exams' challenge. This makes it difficult to collect and analyze clean data. If the intellectual biorhythm actually measures memory potential then a knowledge of potential on exam days may be a determinant in how much preparation is required for the exam.

In general, analyses of accident data is not considered appropriate in analyzing biorhythms since accident data isolates the analysis to the low performance potential area of the biorhythm. This single class of data prevents the use of the entire statistical model. For example the Chi-Square Contingency Test and the Coefficient of Contingency are not applicable as suggested. However application of both the Chi-Square Goodness-of-Fit Test and the KS Test established the existence of a non-uniform distribution of below average performance days. One may wonder what is the effect of considering a natural built in variance due to the uncertainty of the exact hour of birth and possibly the exact time of the observed event. Between critical days (above and below average performance) the variance has a negligible effect on whether the biorhythm is present. However it has a profound affect on the criticality in that the assumption of variance increases the chance probability of an event occurring on a critical day. Further dichotomizing the time-loss and non-time-loss accidents allowed the assessment

of the severity of the accidents. The refinement in classification resulted in applying the Chi-Square Contingency Test and the Coefficient of Contingency. This showed that time-loss accidents (more severe) were dependent upon the biorhythmic day on which they occurred. It is also suggested that the occurrence of critical events is significant. For a sample size of 11 the expected number of events occurring on a critical day is 1.91 with a variance of 1.58 and a standard deviation of 1.25. The fact that four critical observations, lie outside 1.5 standard deviations of the mean suggests the presence of the criticality phenomena. Although it was possible to calculate the exact probability of this event, it is felt that further attempts at accuracy will not be meaningful.

P(3 phy critical days; 1 double critical day;
7 non-critical phy days) =

$$\binom{11}{3,1,7} (.1739)^3(.0124)(.8137)^7 = .02.$$

As illustrated, this can be considered a rare event. On the average it is expected that 1.91 events would occur on critical days. It is also expected that, under a null hypothesis of pure chance, the expected number is not rigid and has a variance of 1.58 and a standard deviation of 1.25. This means that if the occurrence of critical events was pure chance one could expect as few as zero observed critical events or as many as 3.82. The fact that four critical events were observed suggests that criticality does not

occur in a pure chance fashion since more critical events occurred than were expected. Consequently it is felt that a criticality phenomena is present.

Although both analyses do not comprise a validation, each analysis completely supports the theory in a very strong sense.

VII. CONCLUSION

Although biorhythmic phenomena is considered esoteric and attributed to the occult sciences, the possibility that such isochronic phenomena exists should not be dismissed. As suggested there are scientific methodological ways of investigating the theory. The method presented here is not considered the only method. Preliminary investigations suggest the validity of the theory, however, only a scientifically based validation will be accepted by a scientific community.

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